Water Quality Monitoring Network Optimization

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U.S. Department of the Interior
U.S. Geological Survey

Presentation overview

- Part 1. Data requirements
- Part 2. Statistical methods
- Part 3. Optimization method

Case study: Great Smoky Mountains Water Quality Monitoring Network (GRSM)

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Why optimize?

- Must meet budget constraints
- Reallocation of funds to other monitoring efforts
- Determine if additional monitoring efforts are needed
- Reduce duplicated efforts
- Assessment of historical data

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What data are available?

- Land cover
- Soils
- Vegetation
- Geology
- Watershed characteristics
- Stream information
- Historical water quality data (DLF)
- Biological monitoring data (DLF)
- Streamflow

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GRSM Data

- Water Quality – pH, ANC, conductivity, nitrate, sulfate, chloride, sodium, and potassium
  - Quarterly grab samples
  - Period from 1996-2001
- Watershed characteristics
  - Geology
  - Stream morphology
  - Vegetation
- Collocation information
  - Benthic study
  - Brook trout study
- Costs
  - Laboratory
  - Site access

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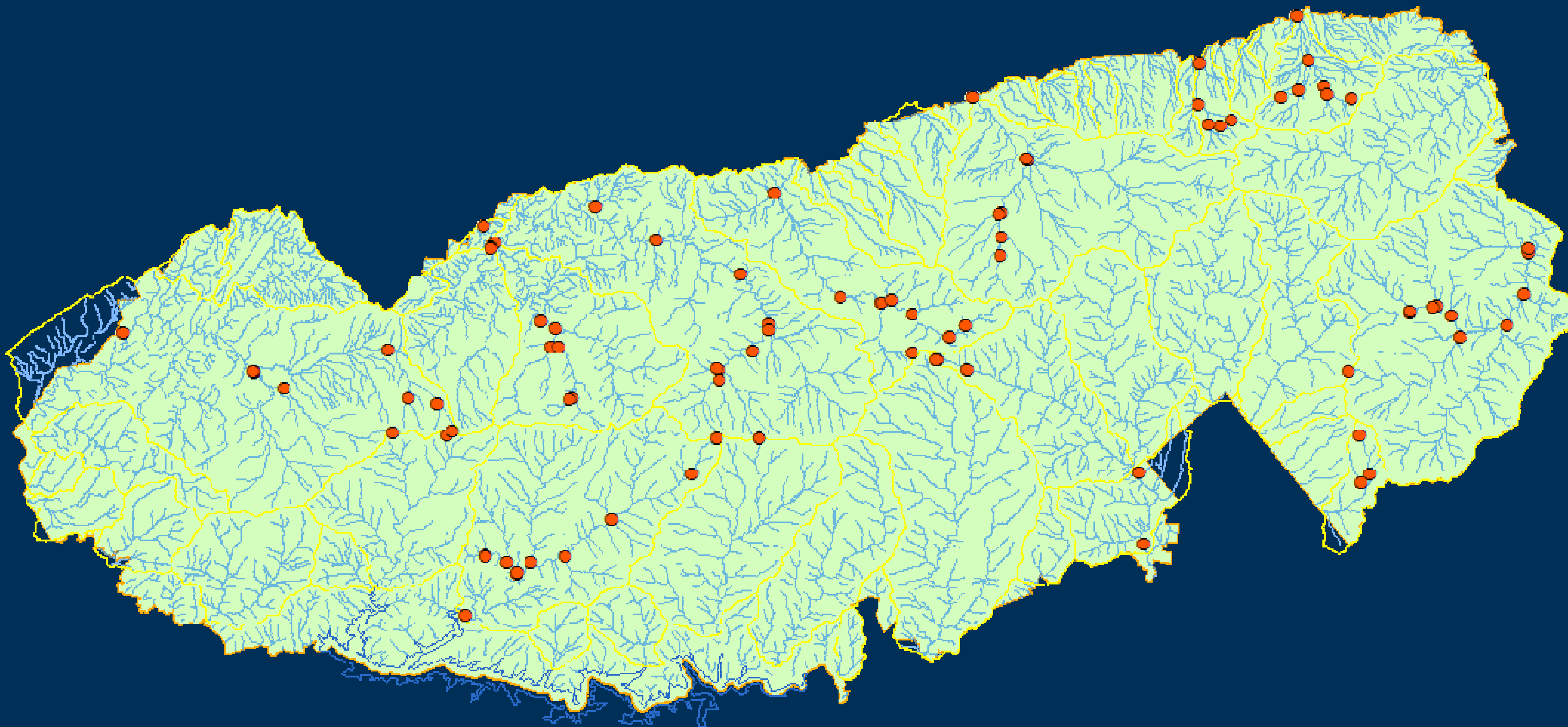
Great Smoky Mountains Network



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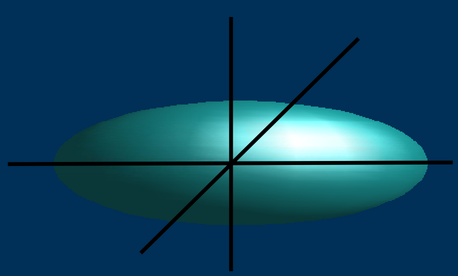
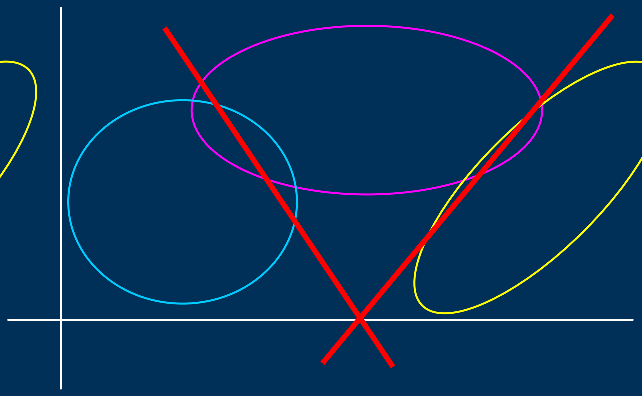
The statistics toolbox

- Data screening (descriptive statistics)
- Principal components analysis (PCA)
- Cluster analysis (CA)
- Discriminant analysis (DA)
- Robust PCA

Multivariate statistical methods

- Principal components analysis – reduce the dimensionality of the data
- Cluster analysis – group similar sampling sites together the use cluster centroid distance as a measure of variability explained within each cluster
- Discriminant analysis – validation test for the clusters that were formed using cross-validation method





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Optimization needs

- Mechanism for assigning benefits to sampling sites
- Objective function to score and compare different network designs
- Knowledge of any special circumstances that may need to be addressed in the benefit assignment or programming phase

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Special considerations (GRSM)

- Small clusters should remain intact – only clusters with large memberships should be targeted
- Ensure that all water quality, geology, morphology, and vegetation clusters are represented in the final network

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Determining costs and benefits (GRSM)

- Total network cost of \$69,200
  - \$19,200 per year for access and sampling time (640 man-hours X \$30/man-hour)
  - \$50,000 per year for laboratory, technical, administration, and overhead (approx. \$602 per site/year)
- Total Benefit = 1.2 X \$69,200 = \$83,040
  - Basis: Benefit should outweigh cost
  - Basis: 20 percent return is a modest expectation
  - $BENEFIT_{TOTAL} = \$83,040$
- Cost of p-sites:

$$\boxed{COST_p = \sum_p LABCOST + \sum_p ACCESS}$$

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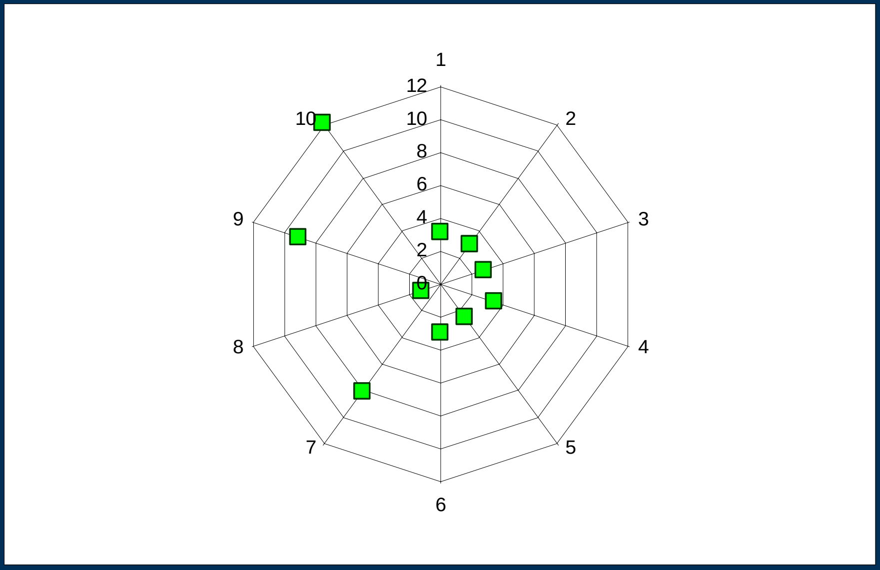
Apportioning for site benefits (GRSM)

- Sites ranked using distance from centroid
- Ranks are then summed across categories - one score for each site, Ψ_i

$$\Psi_i = \omega_1 W_i + \omega_2 G_i + \omega_3 M_i + \omega_4 V_i + \omega_5 C_i$$

- All scores are then summed for apportionment total, Ψ_{TOTAL}

$$BENEFIT_i = \frac{\Psi_i}{\Psi_{TOTAL}} \times BENEFIT_{TOTAL}$$



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Optimization using simulated annealing

- Heuristic method based on the thermodynamics of heating a body to a temperature such that all bonds have been broken between molecules
- Controlled cooling is then applied such that the molecules can arrange themselves to a minimal energy state
- Simulated annealing escapes local minima/maxima
- Maximize the objective function

$$\boxed{NETBENEFIT_p = \sum_p BENEFIT - \sum_p COST}$$

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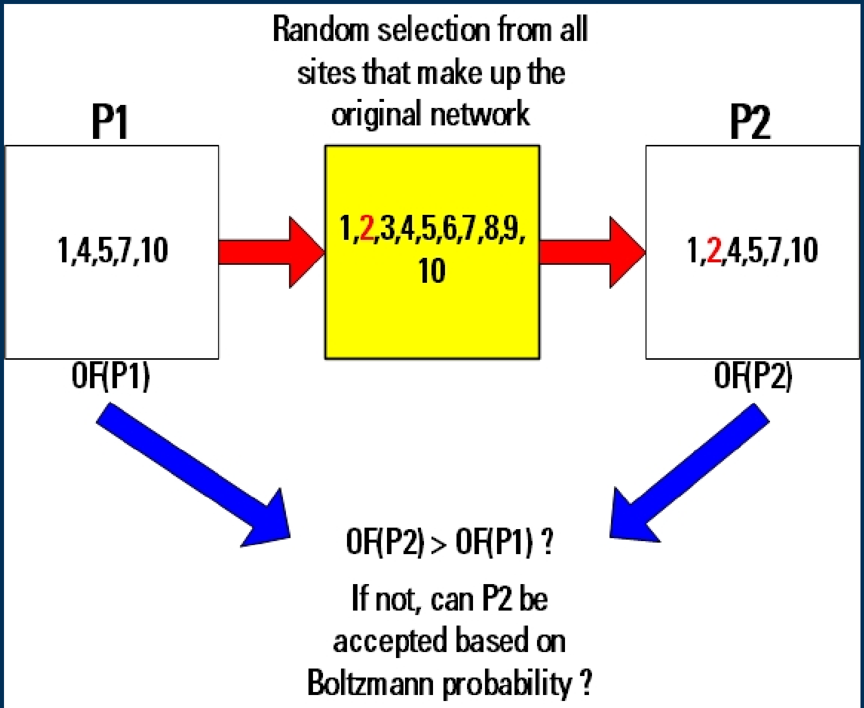
Basics of Simulated Annealing

- Start with a network (P1)
- Randomly choose one site from all sites in the network
  - If IN the P1 network, test OF for removal (P2)
  - If OUT of the P1 network, test OF for addition (P2)
- IF OF(P2) < OF(P1), Can P2 still be accepted using the Boltzmann probability?
  - As temp gets lower it becomes harder for a network to be accepted using the Boltzmann probability
- Continues until the termination loop is satisfied



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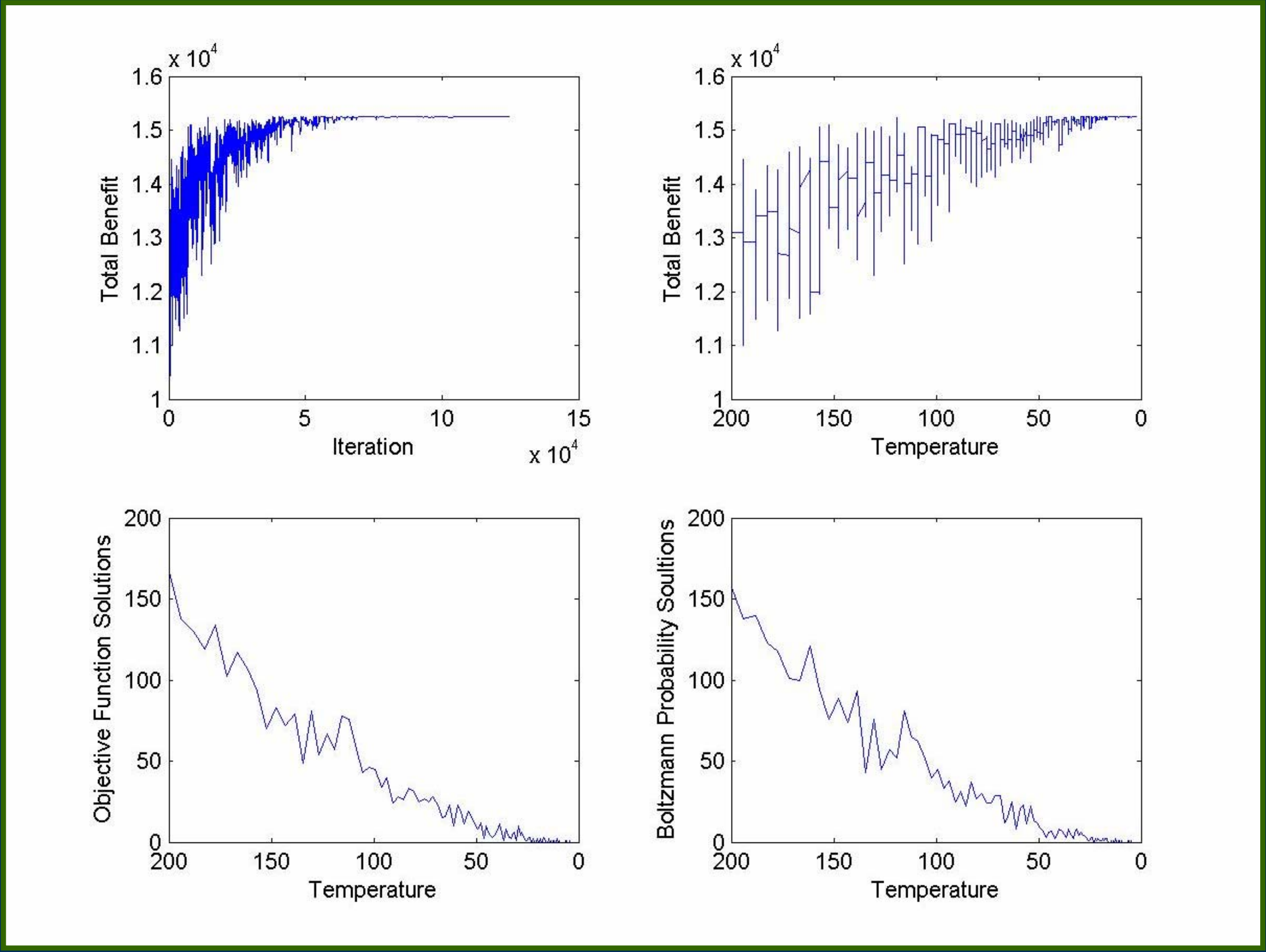
Objective function tracking



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Network optimization

Simulated annealing program written for two cases

- First case (SA1) – Simulated annealing is performed on the network to determine the overall optimum network configuration
- Second case (SA2) – user-specified (n) number of sites desired in the final network. The optimized network will contain exactly n-sites
  - Provides a validation for SA1 results
  - Provides a logical format for considering other sampling sites to be retained or discontinued

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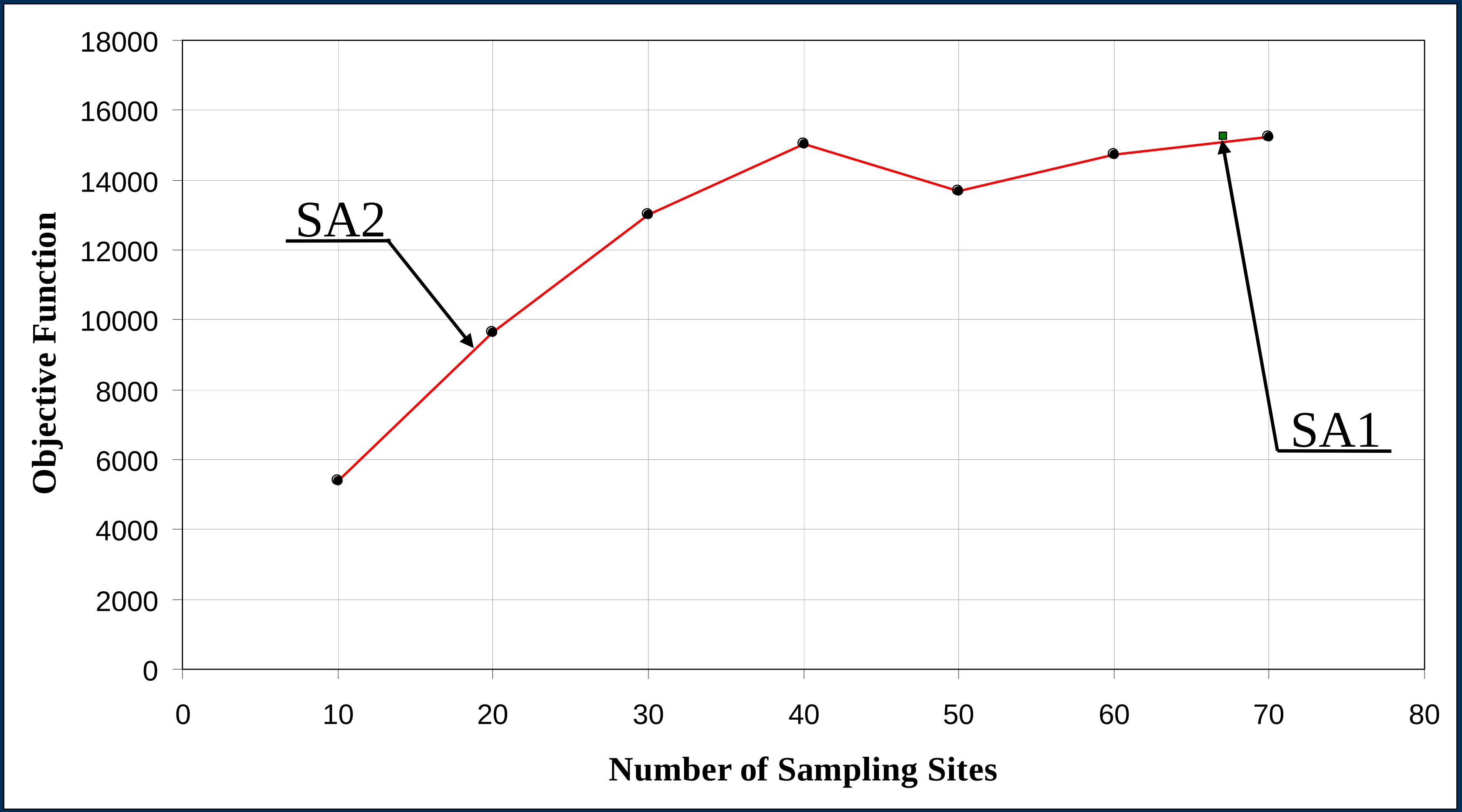
SA2 results – *n* best sites



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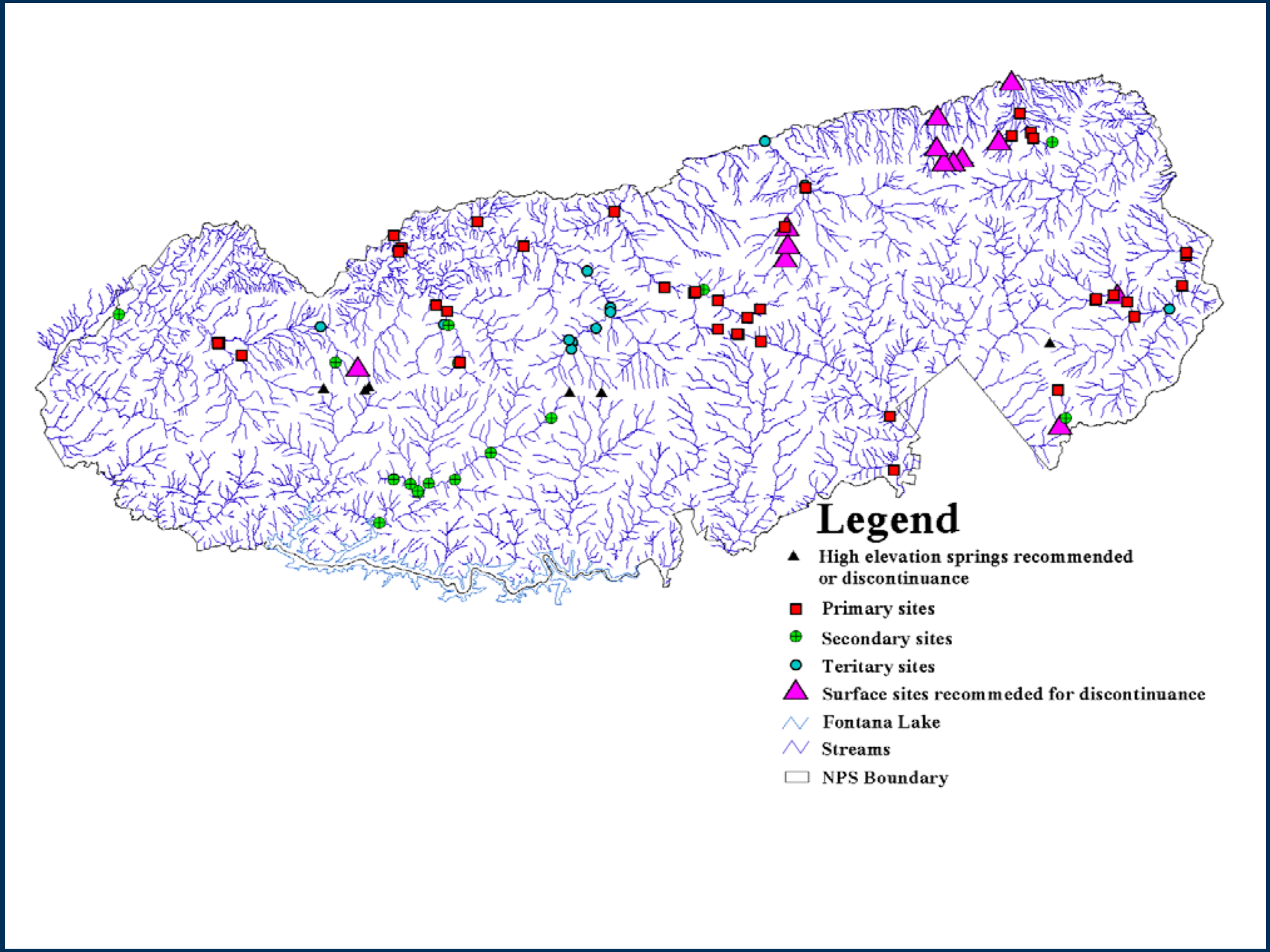
Redesigned Network (GRSM)



Sensitivity analysis

- Vary weighting factors
- Test individual categories
- Vary the cost multiplier for benefits

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Temporal assessment

- Resampling of data at different sampling frequencies
- Compare trend test results at different sampling frequencies to the trend from the original high-frequency data (MIN)
  - Boxplot analysis
  - Mann-Kendall test for trend
  - Time series regression
- Identify frequency where dependency becomes an issue using the autocorrelation function (MAX)
- Confidence level to reliably detect a trend within a certain number of years

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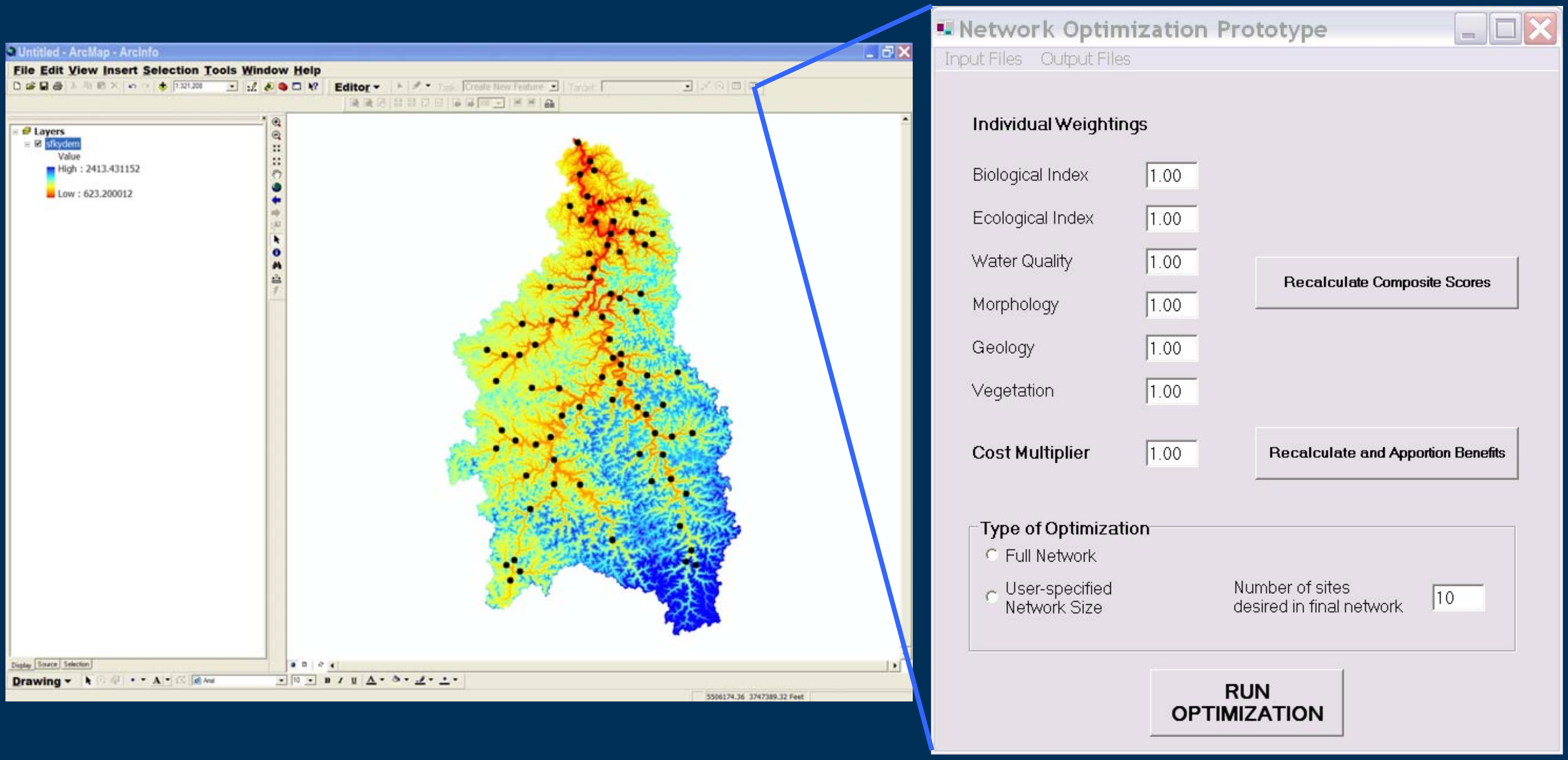
ArcMap Tool Application



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The end